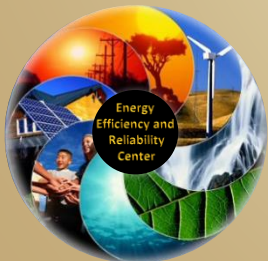


Street Lighting Technology Research

In conjunction with
Indiana Municipal Utility Group
Indiana Department of Transportation

Prepared by
Energy Efficiency and Reliability Center
Professor Robert Kramer, Ph.D., CEM, CDSM, CEA
Purdue University Northwest
Hammond, Indiana



Modern Lighting Benefits

- Reduced cost (electric and maintenance)
- Increased reliability
- Whiter light than high pressure sodium.
- Energy savings → reduced emissions
- Improved safety
- Improved perception of neighborhood
- Reduced maintenance and longer life
- Light levels can be controlled by use and time of day or activity level

Iterative implementation process that considers the specific needs of a region

- Indiana Municipal Utility Group (IMUG) / Energy Efficiency and Reliability Center (EERC) has been testing luminaires for ~4 years and has identified a list of luminaires that provide the most benefit.
 - Testing conducted in the laboratory at EERC and in the field (IMUG sites).
 - Input from IMUG members was used as a critical resource in the evaluation process.
- Efforts now expanding to consider light distribution and optimization design and pole top conversion.

Modern Lighting Is Being Widely Implemented

- In the City of Los Angeles "Bright Lights, Safe Nights" program a total of 167,028 (March 2016) of the existing 210,000 street lights have been converted from principally HPS to LED.
- Crime statistics comparing 2009 to 2012, as reported by the local police, indicate < in Theft From Vehicles of 10.67%, a < in Burglary-Robbery-Theft of 6.40%, and a < in Vandalism of 10.90% for a total decrease in these categories of 8.9%.

- In shifting to an optimized white light, visibility is increased resulting in both increases in safety as well as the perception and enjoyment of the community at night.
- As stated by the Urban Age Institute, "It is however also becoming apparent that modern LED lighting increases citizens sense of safety, makes cities more inviting for tourism, and increases productivity at our workplaces (without having to work harder)."

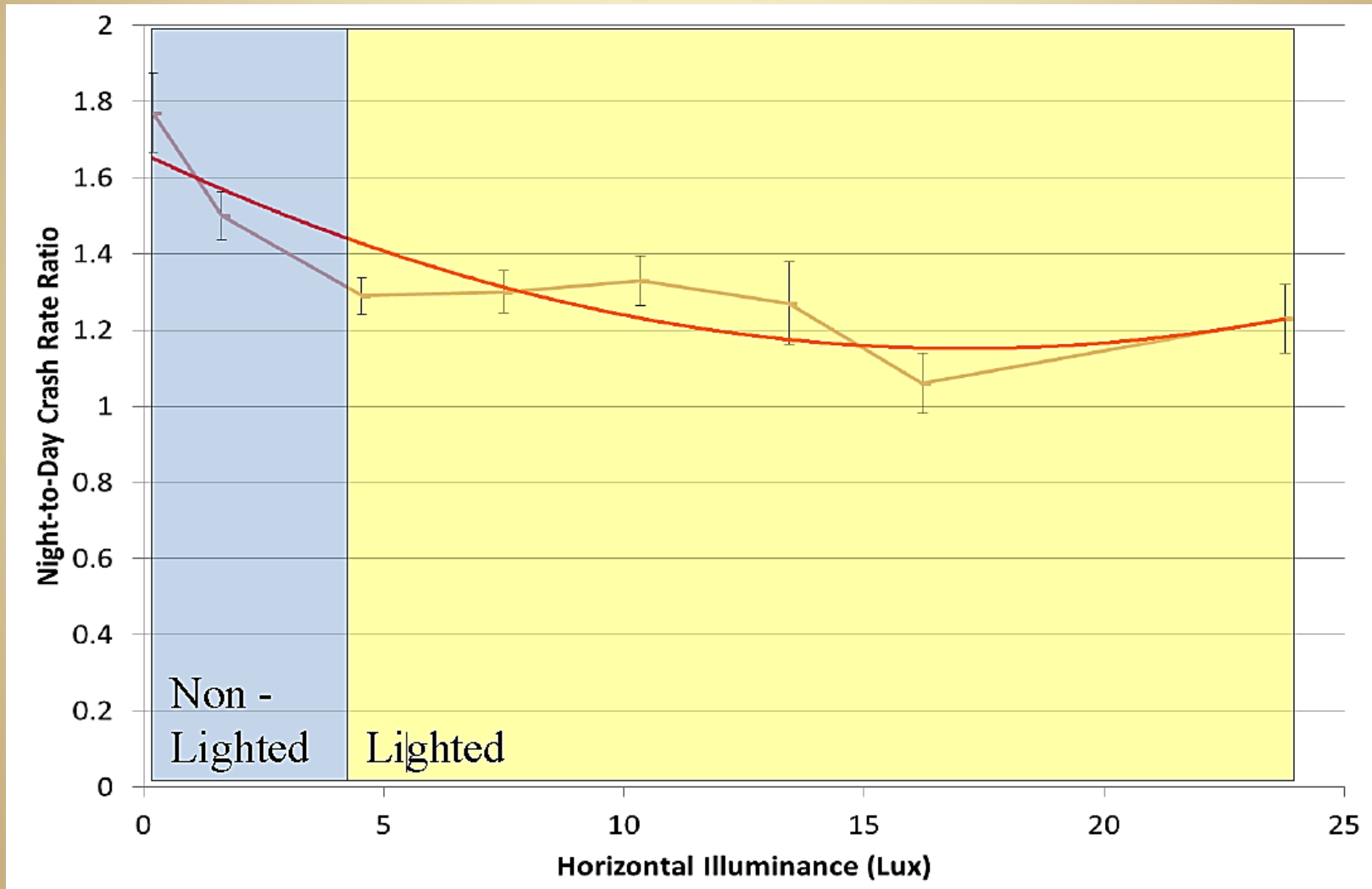


Before
195 W HPS



After
88 W LED
55% energy savings

Virginia Tech Research Study Compared the lighting level to crash rate ratios for 83,000 crashes and 2000 miles of roadway lighting



Local Issues

- There isn't a generic luminaire that can satisfy all needs.
- Maximizing value requires consideration of luminaire design for a particular application.
- The number of luminaire types can be controlled and most of the benefit can still be obtained.



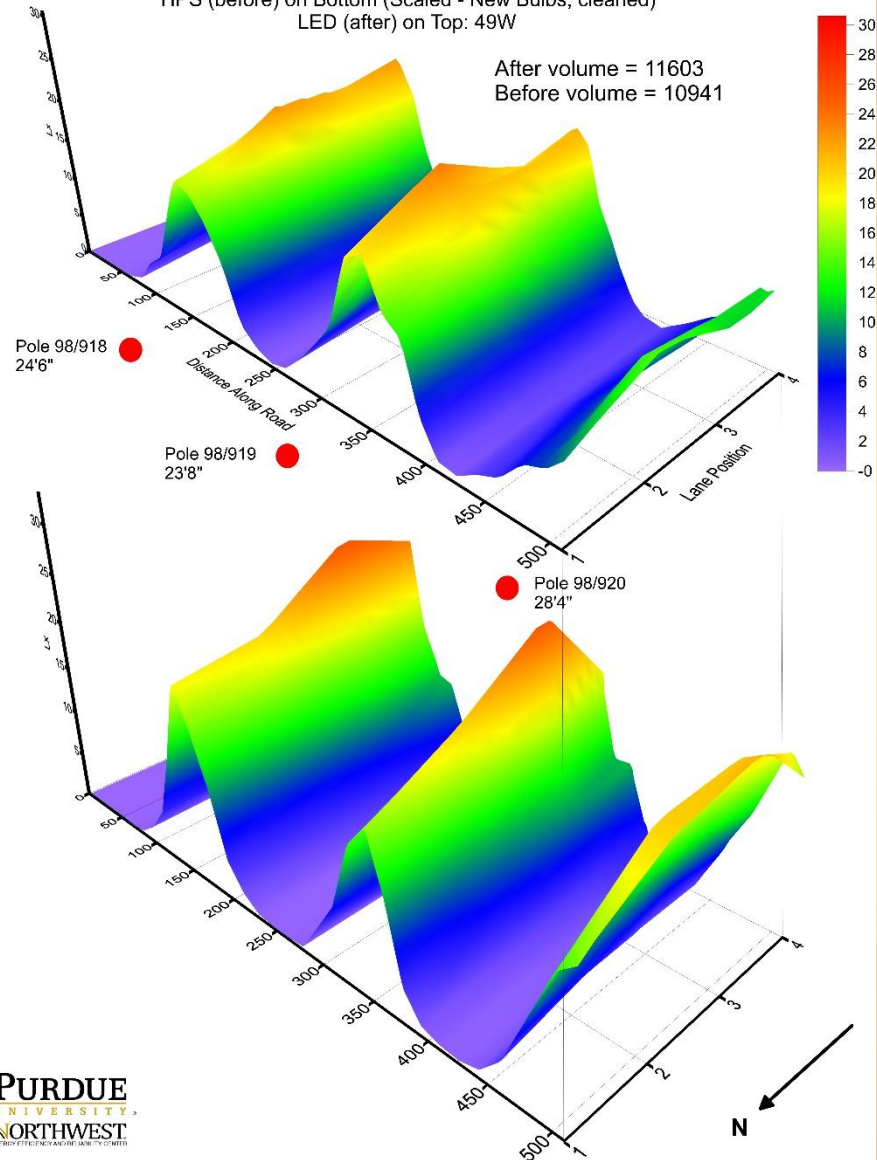


Use an iterative implementation process that considers the specific needs of a region

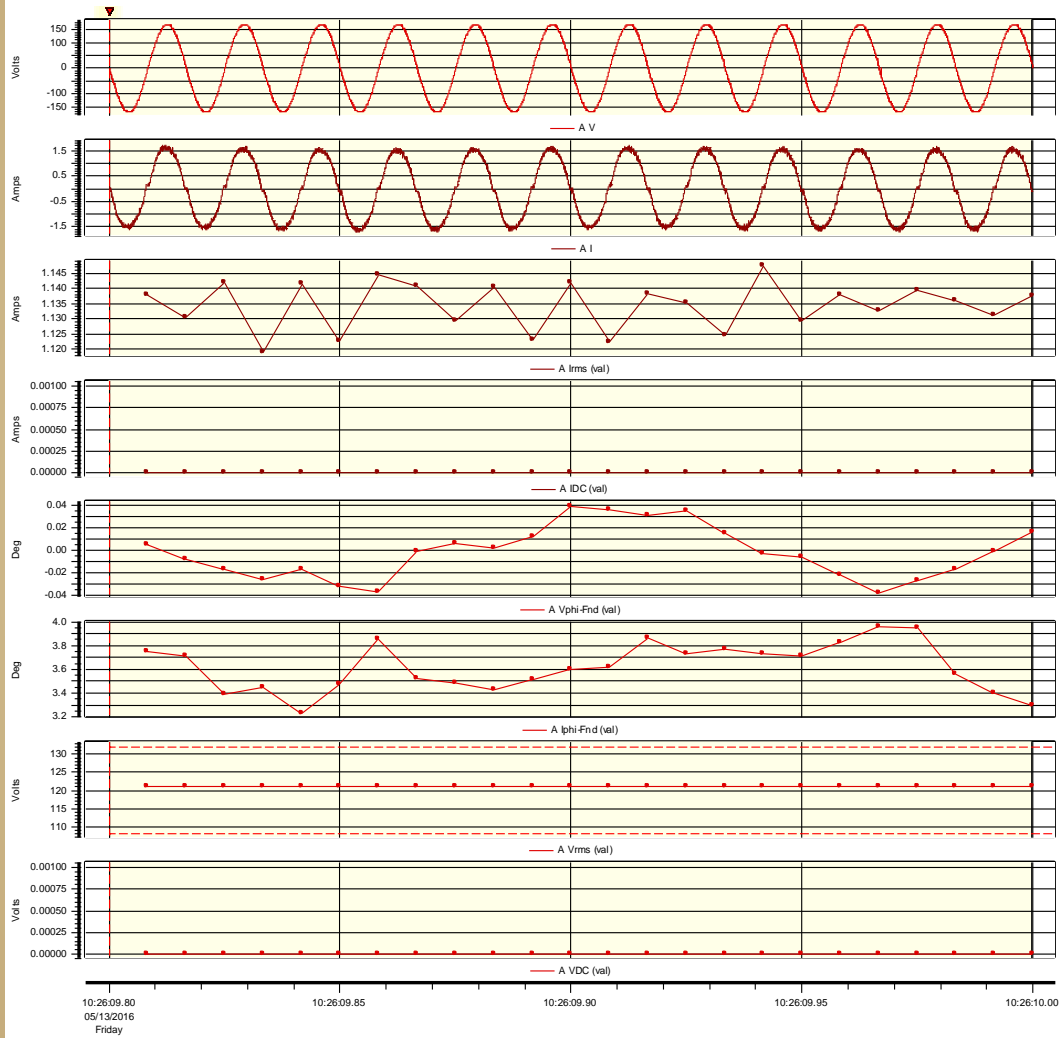
- A cooperative involvement of the parties where everyone wins maximizes value.
- There are reported successes and failures
 - Often the negative outcomes resulted from lack of a comprehensive design as well as use of equipment that was not designed for the particular application or was technically behind the current state of the art.

100W HPS Equivalent
HPS (before) on Bottom (Scaled - New Bulbs, cleaned)
LED (after) on Top: 49W

After volume = 11603
Before volume = 10941

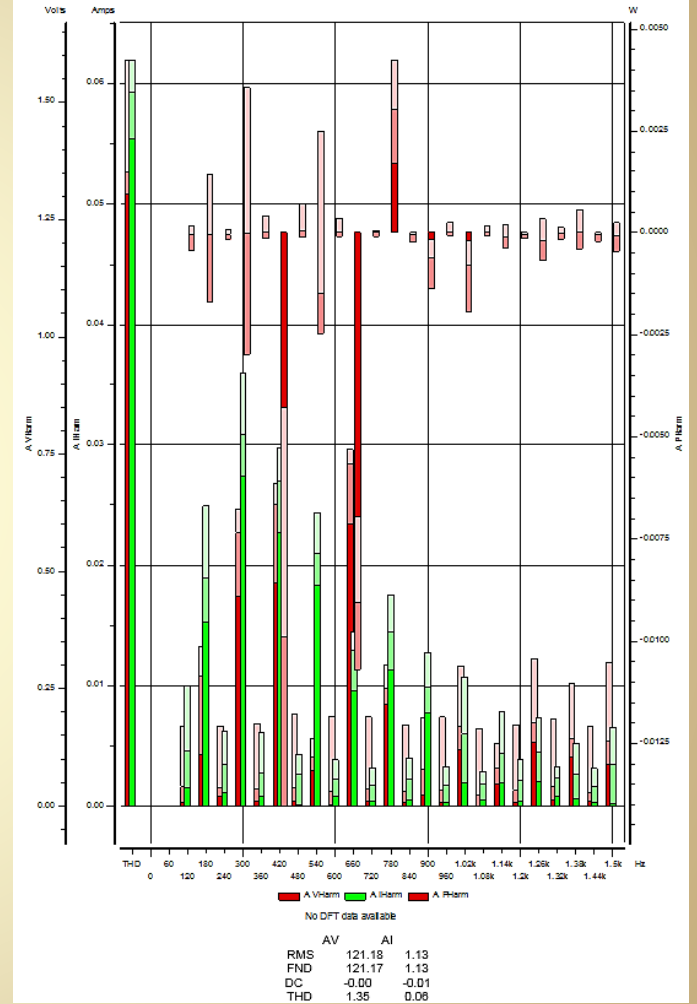


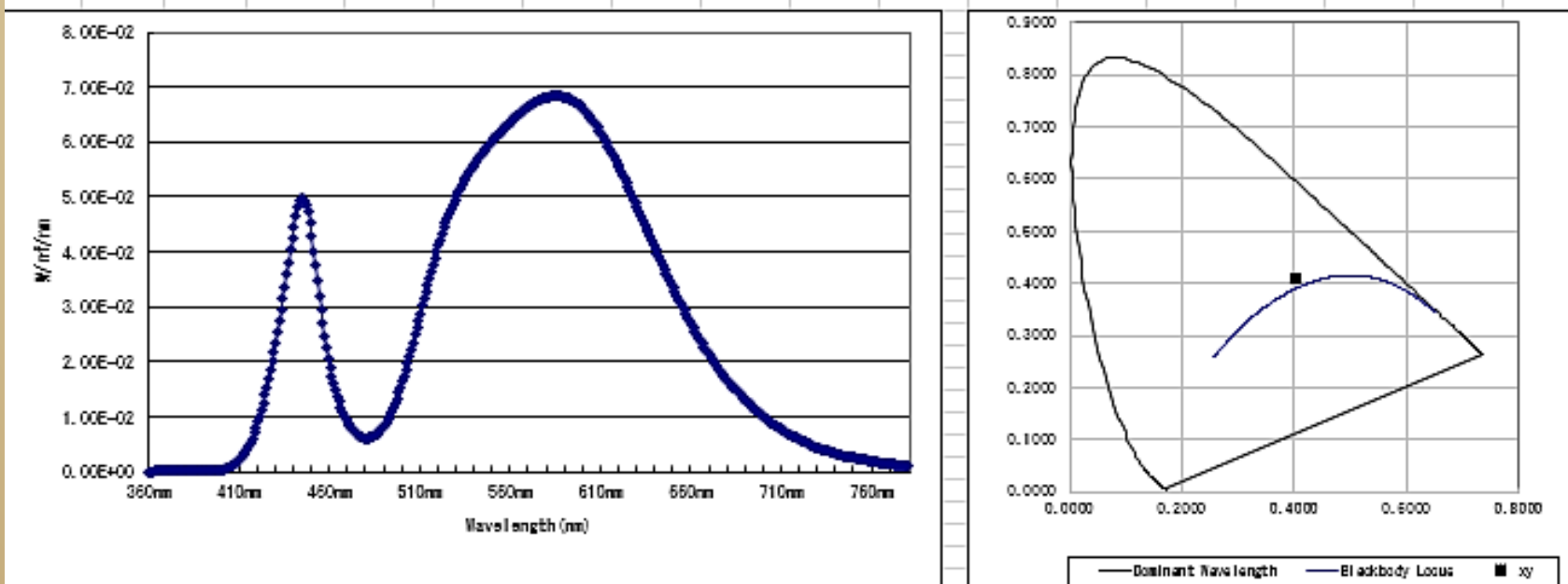
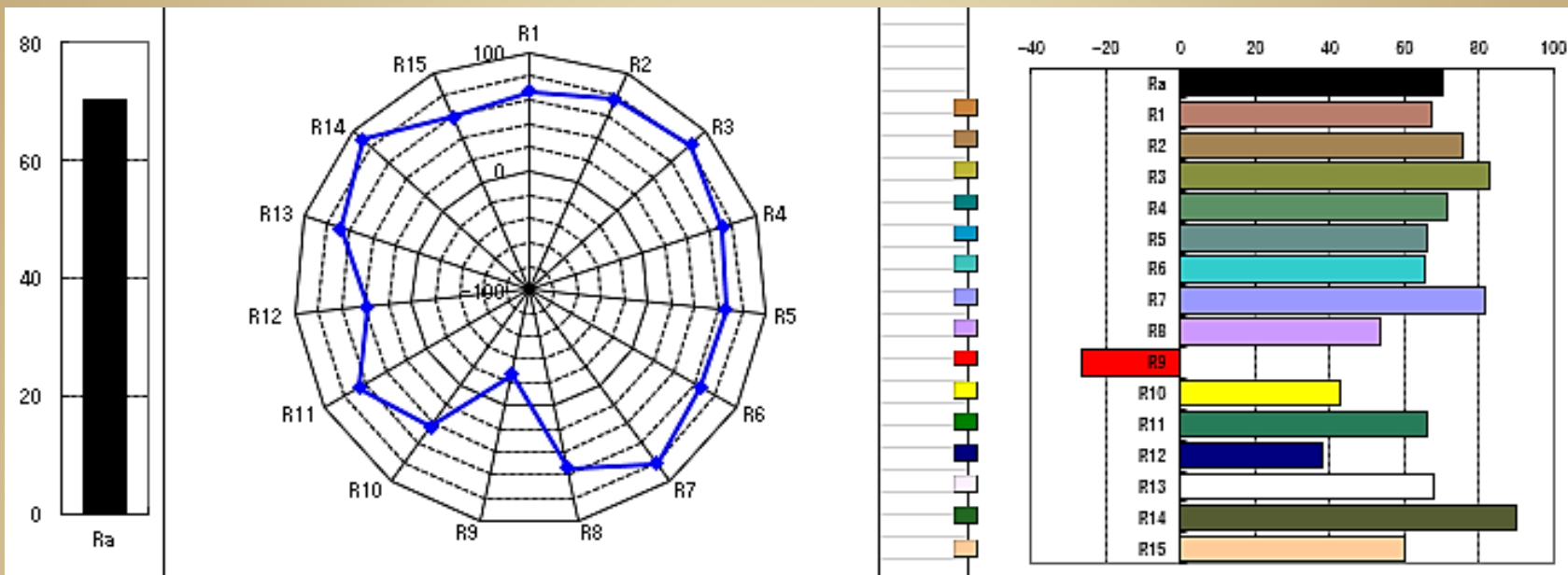
Event Details/Waveforms



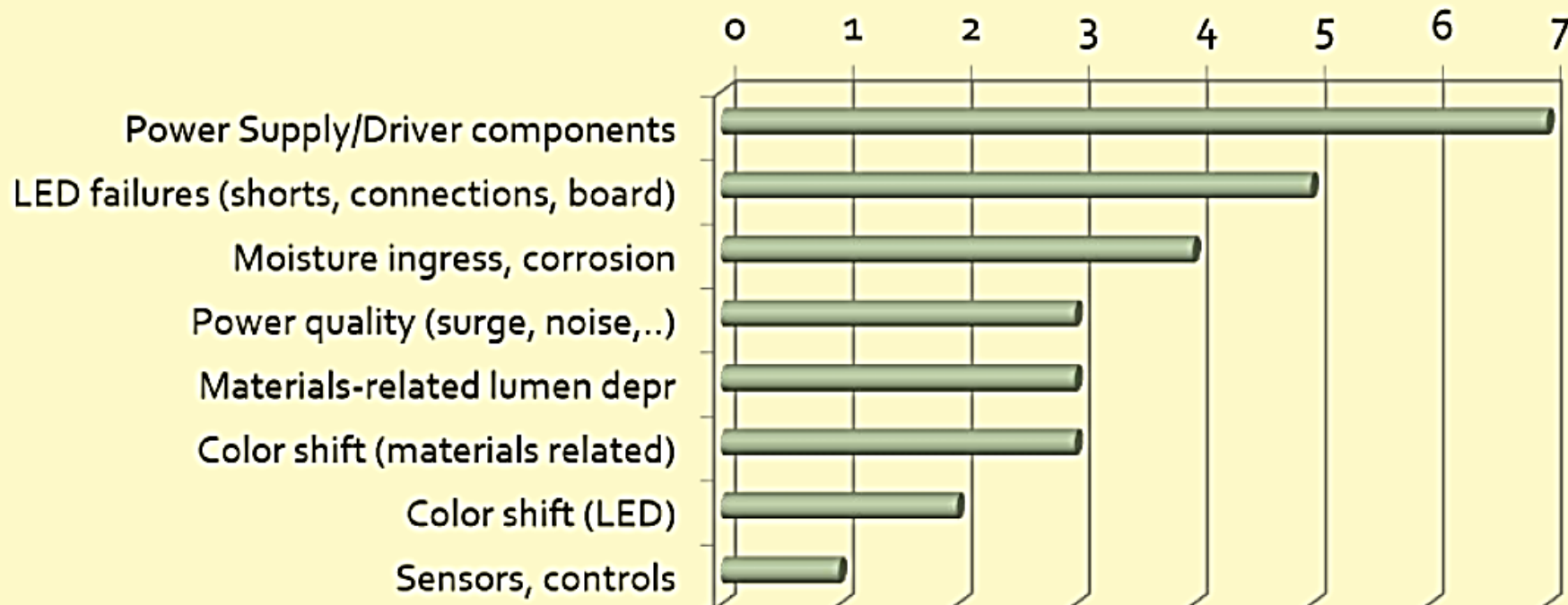
Event #1 at 05/13/2016 10:26:09.800
Timed

Waveform harmonics

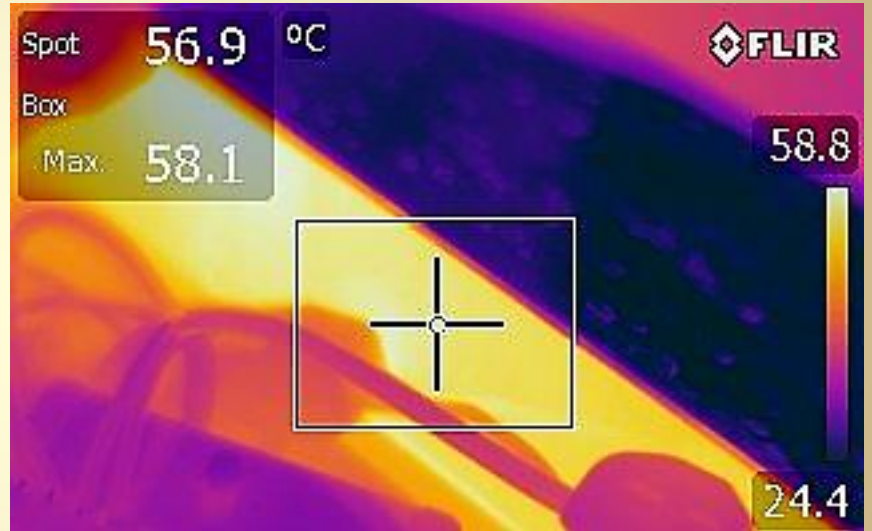




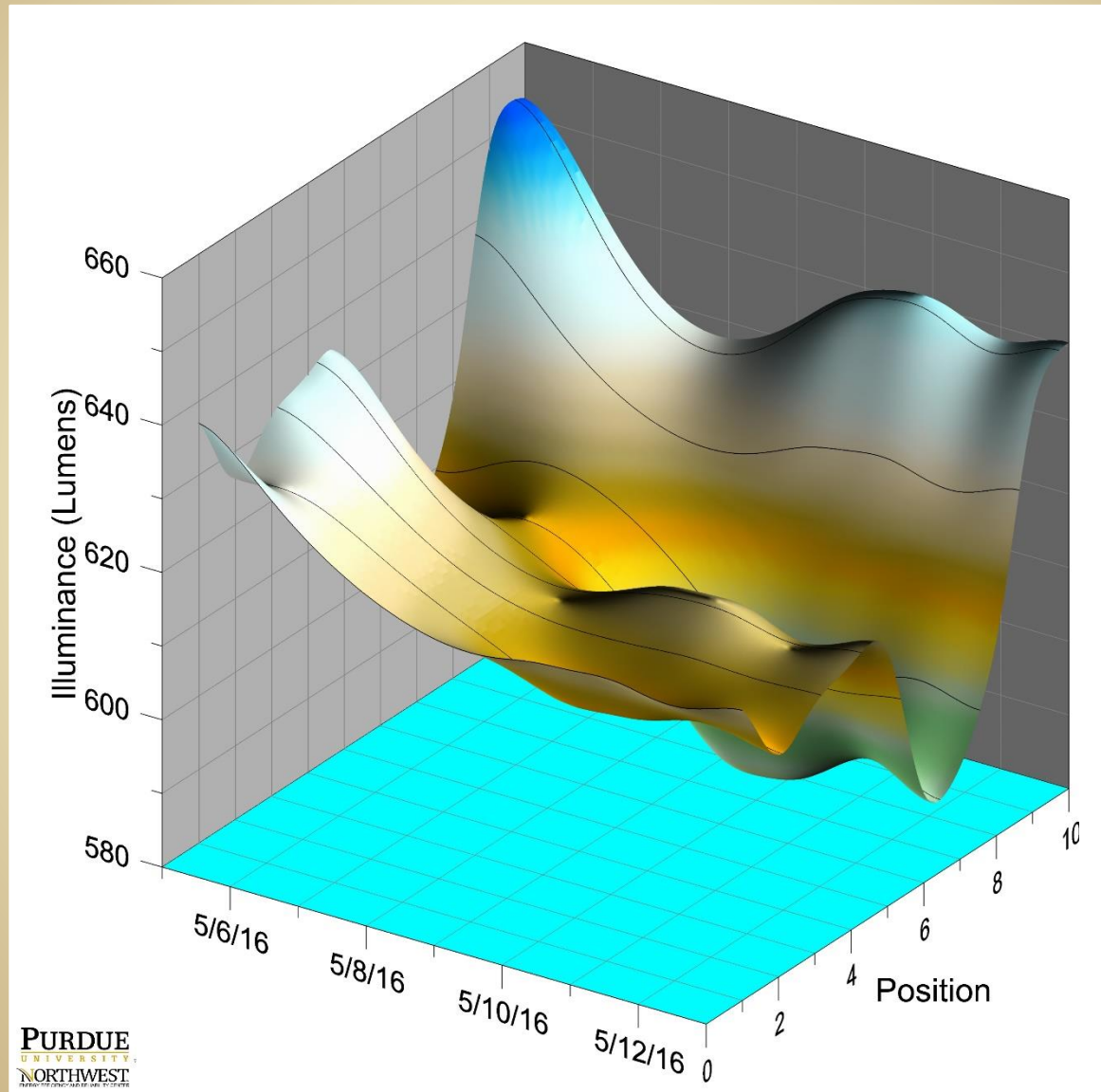
"Favorite Failures"



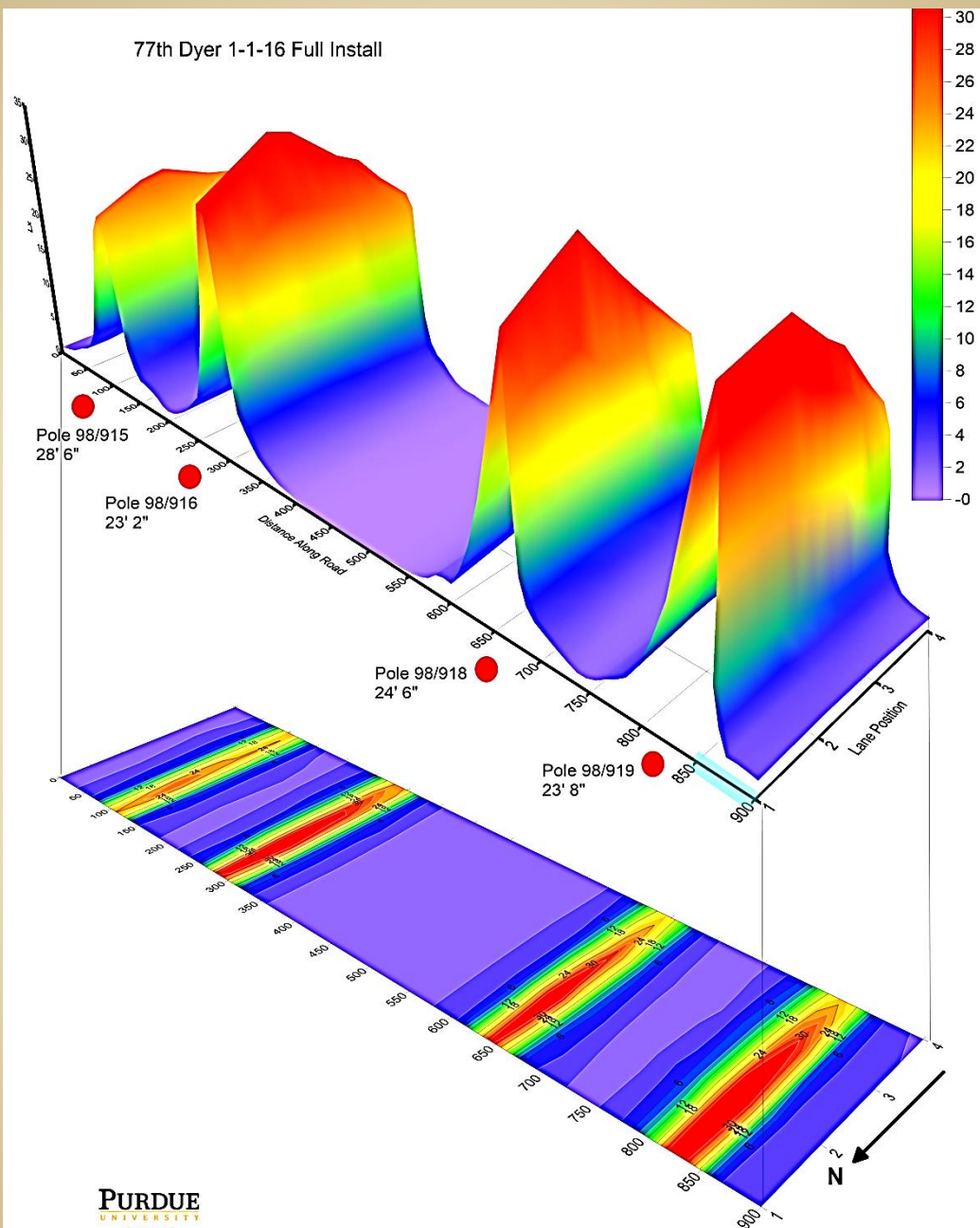
Driver Reliability Testing



Initial Lumen Depreciation



77th Dyer 1-1-16 Full Install



Perception of light quality

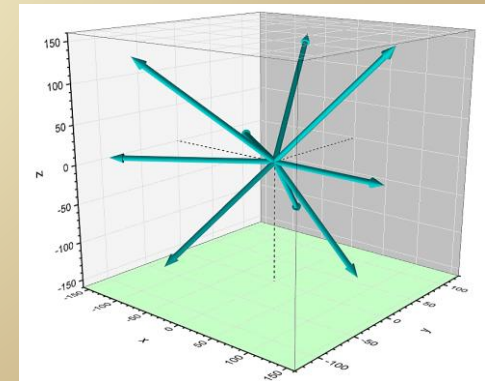
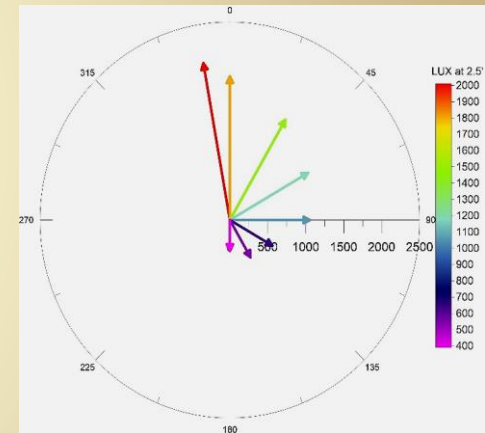
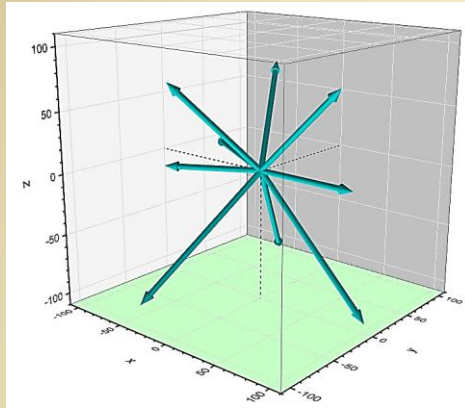
- White light improves perception of objects and ability to sense motion (human eye is the light sensor) when compared to monochromatic yellow light from HPS.
- Perception of glare can vary from person to person.

LEDs can cause glare, which may negatively impact adoption if not implemented correctly





Post Top Retrofit Unit Examples



Impact on Neighborhoods

- Lighting assists in efforts to revitalize blighted or deteriorating neighborhoods.
- In street light performance tests conducted by the EERC in the field on city streets it has been noted that the white light of LED luminaires makes it easier to detect vehicles, detail and motion in the areas illuminated by LED street lights as compared to HPS light.
- It's clear that LED street lights reduce safety concerns related to traffic during the data collection process.
- Transitioning to LED street lights substantially improves nighttime vision, safety, and security thereby helping improve neighborhoods as a whole.
- LED benefits contribute to revitalization of areas by improving both the quality and the penetration of lighting.
- Good road lighting contributes to a feeling of security by residents.

Opportunity to introduce new luminaires that have much higher efficiency and improved light quality as compared to HPS or mercury vapor.

- HPS luminaires are often not readily available as the technology is being displaced by LEDs.
- If sequenced in a consistent manner, a graded program over time will provide significant savings in energy and maintenance and overall improved value – Probabilistic Life Cycle Cost Analysis

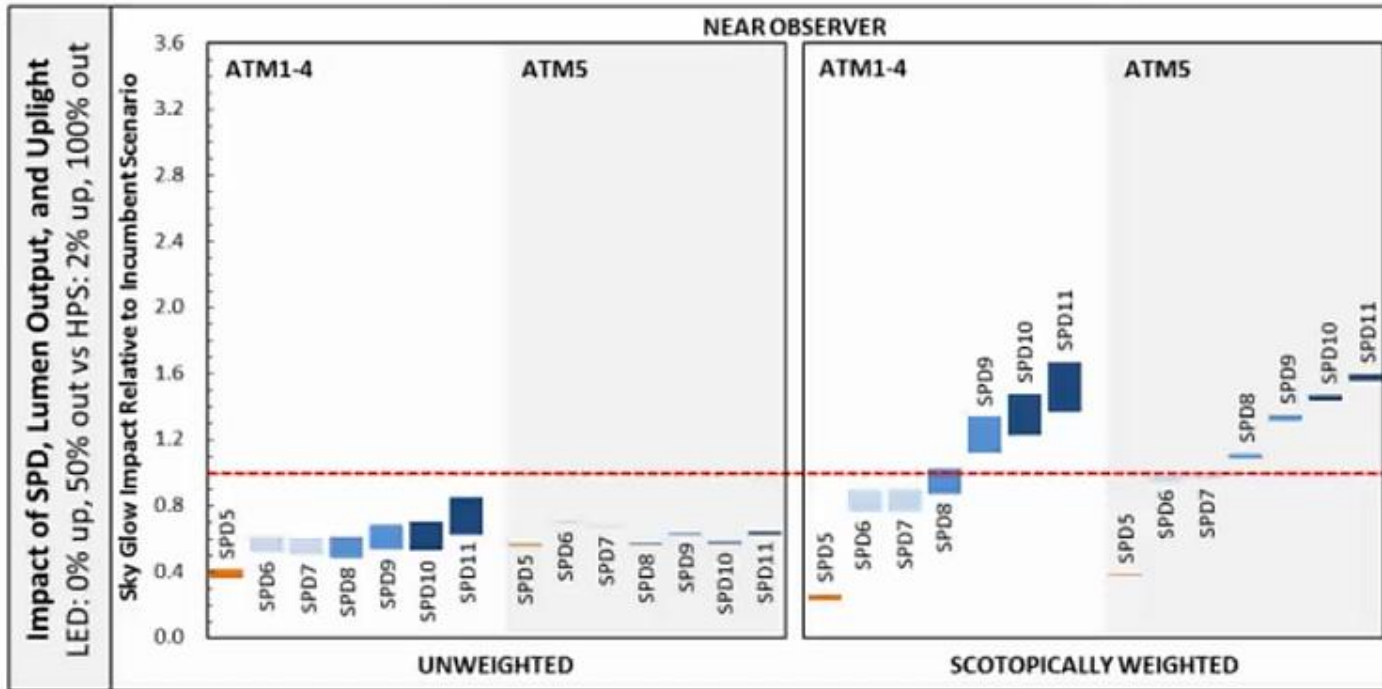
We Now Have An Opportunity To Make Some Significant Community Improvements

- In many areas street lights are reaching end of life.
- White light options such as LED can increase energy efficiency, security and roadway safety.
 - Most residents are happy with the performance of the newly installed lighting.
 - Some residents have expressed interest in increasing lighting levels and expanding coverage area.
 - Some residents have expressed a desire to restrict lighting and concentrate it more on roadways.
 - IMUG/EERC has developed a recommended list of products that maximizes economic and environmental value, reliability, maintenance, and addresses concerns from all groups.
- We have an obligation to develop an approach that authentically maximizes the benefits and minimizes risks.
 - Visibility, reliability, safety, security, maintenance, environmental and biological aspects are critical.
 - Over the last 5 years IMUG/EERC has done extensive theoretical, laboratory, and field testing to develop an optimized list of recommended options to meet these goals.

- One important aspect that is currently not entirely clear is how to maximize the characteristics of the light.

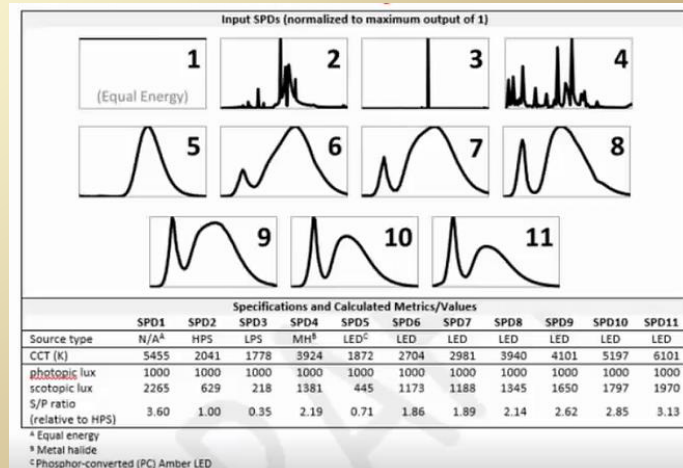
- Some groups are referring to color correlation temperature (CCT) as a key variable to be considered.
 - It is now clear that CCT is not appropriate for this purpose and we must be willing to do the additional work to consider hard scientific facts if a decision is to be made that makes the situation better rather than worse.
 - This is not a simple issue and simplistic criteria can lead to negative consequences.
 - Sometimes lower CCT light can cause more negative biological consequences than a higher CCT value.
 - We need to delve deeper into the science, beyond just CCT, and do the required work to make sure that we don't make erroneous choices and make the situation worse.
 - Regarding Dark Skies issues it has been shown that a properly designed LED system can have no more or less of an influence on sky glow when compared to current HPS installations.

Impact of SPD, 50% reduction in output, and 0% uplift



Increasing CCT

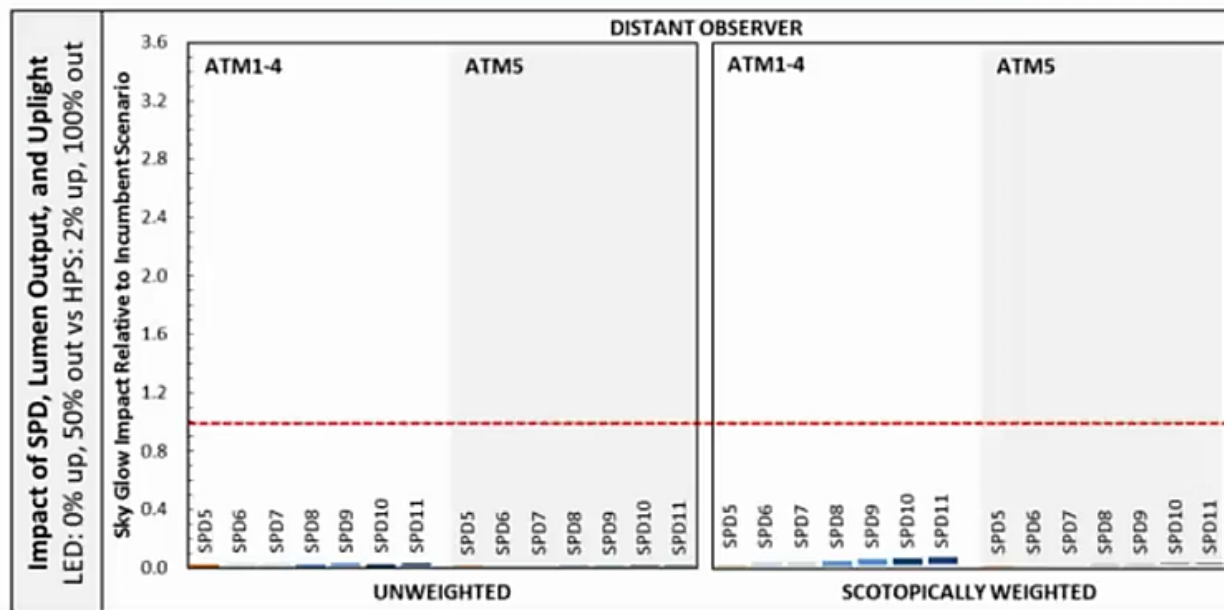
Near Observer



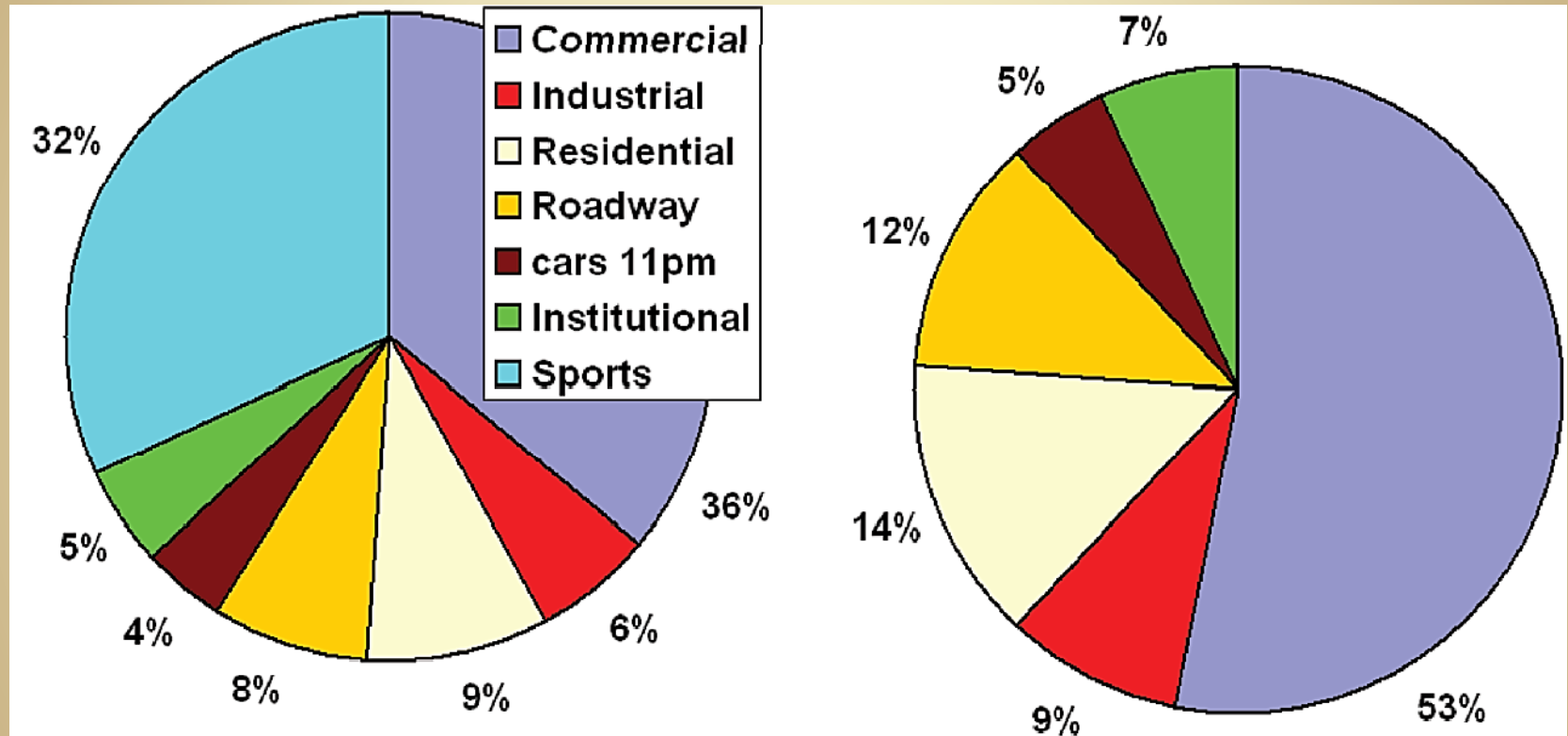
Source: DOE Report: "An Investigation of LED Street Lighting's Impact on Sky Glow", April 2017

And almost eliminates sky glow (by 95+%) for the distant (40 km) observer, from the street lighting system

Impact of SPD, 50% reduction in output, and 0% uplift



Sources of Sky Light



A Little History to Set the Stage

- Starting in the 1980 time frame it was common to install High Pressure Sodium (HPS) technology
- Previously, for a large part, street lighting was Mercury Vapor
- The CCT for Mercury Vapor is 6800K (clear bulb), 5700K with coating – white light
- Before it was replaced the Mercury Vapor, lighting was in place for many years and hence there is experience in Indiana and elsewhere with white street lighting.
- The CCT for HPS 2200K – orange/yellow light.
- CCT is an old metric that is currently not the right parameter to assess possible influences. Details as to why will follow.

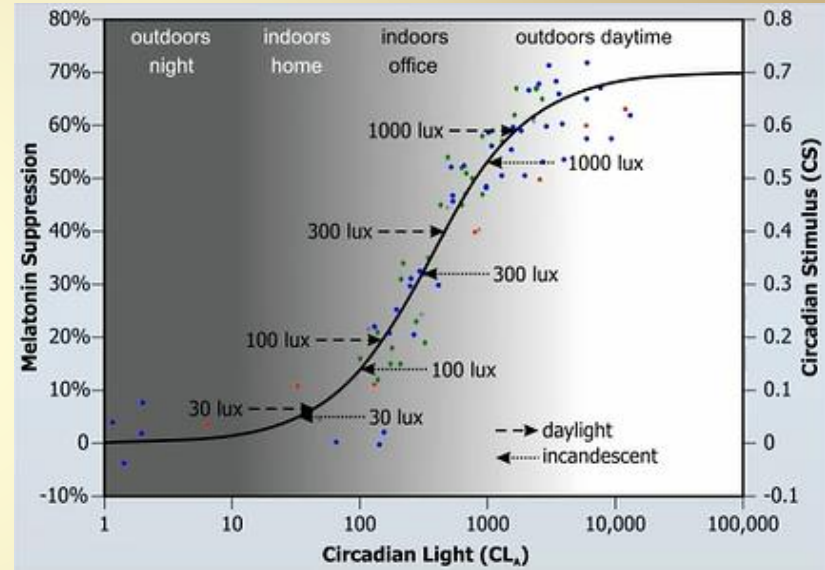
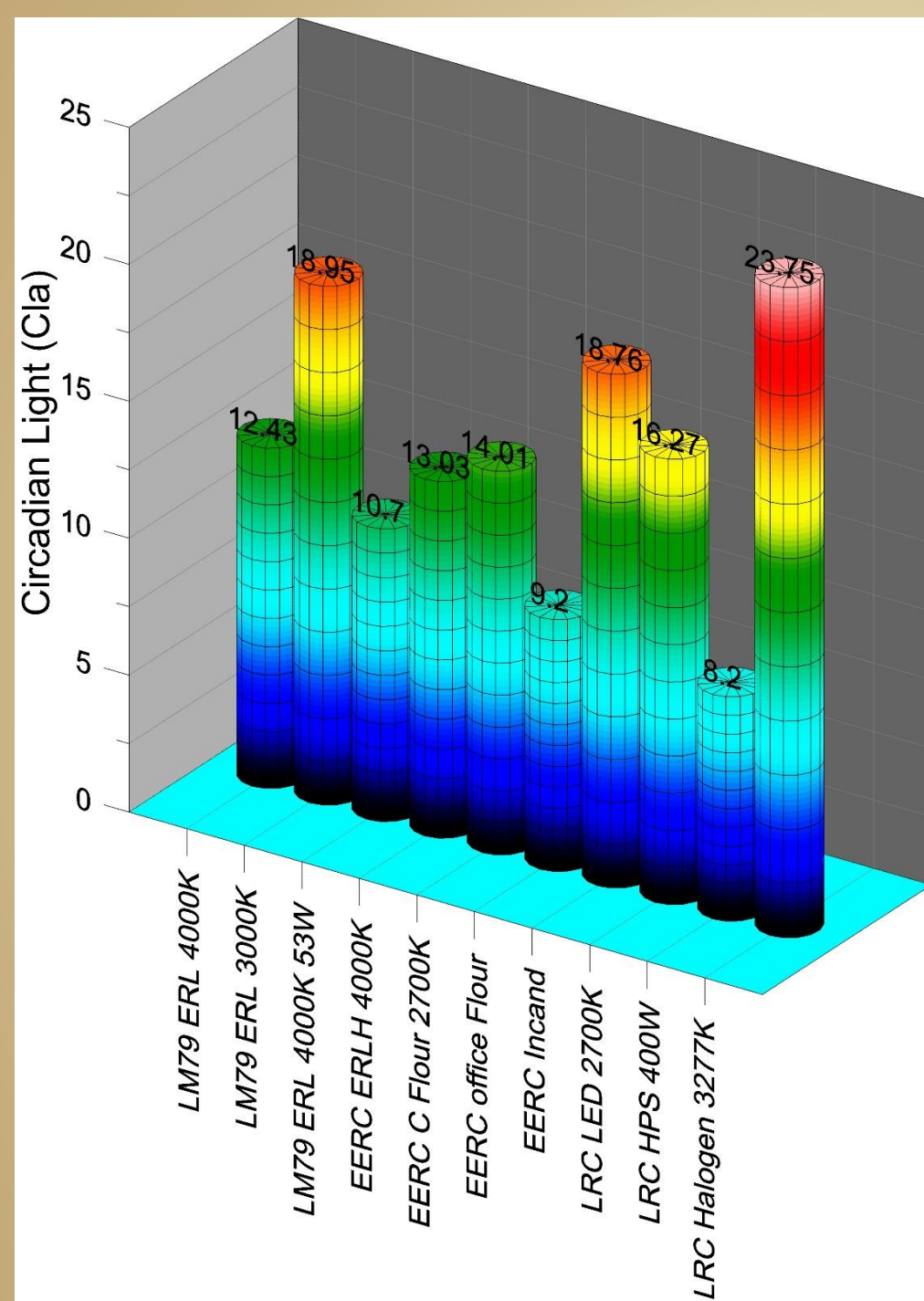
- The Color Correlation Temperature (CCT) is one way to approximate the color of light. It relates to the weighted average of the spectrum of light colors that are emitted by a perfect emitter and absorber of electromagnetic energy (light in this case) referred to as a black body in thermal equilibrium at a specified temperature measured in the SI units of temperature, Kelvin (K).
- 4000K, 3000K, and some 2700K street light options are available.
- The 4000K CCT luminaires offer benefits of approximately 2-4.3% improved efficiency as well as better visibility due to the whiter light when compared to the 3000K option.
- The 4000K CCT luminaires offer benefits of approximately 5-6% improved efficiency as well as better visibility due to the whiter light when compared to the 2700K option.
- Some locations have gone to 3000K or 2700K others are using 4000K.

Source	Actual Luminance (cd/m ²)	Effective Luminance (cd/m ²)	Blue Hazard Weighted Radiance, L_b (W m ⁻² sr ⁻¹)	Permissible Exposure Time per CIE/IEC 62471
Noon sun	1,600,000,000	1,600,000,000	1,200,000	~ 1 s
Blue sky	4,000	4,000	6.2	Indefinite/44 hrs*
Blue LED light box (600 lux at eye)	9,000	9,000	60	Indefinite/4.6 hrs*
Blue LED 500mW, @ 0.5 m	5,100,000	170,000	2620	6.4 min†
Royal Blue LED 3W, @ 0.5 m	2,760,000	1,040,000	15,700	64 s
Fluorescent lamp (T8 RE 4100 K)	10,000	10,000	5.6	Indefinite/50 hrs*
Incandescent lamp filament @ 0.5 m	12,000,000	2,500,000	858	20 min†
White LED (3000 K) @ 0.5 m	17,000,000	1,000,000	388	43 min†
White LED (4000 K) @ 0.5 m	17,000,000	1,000,000	510	33 min†
White LED (6500 K) @ 0.5 m	17,000,000	1,000,000	858	20 min†

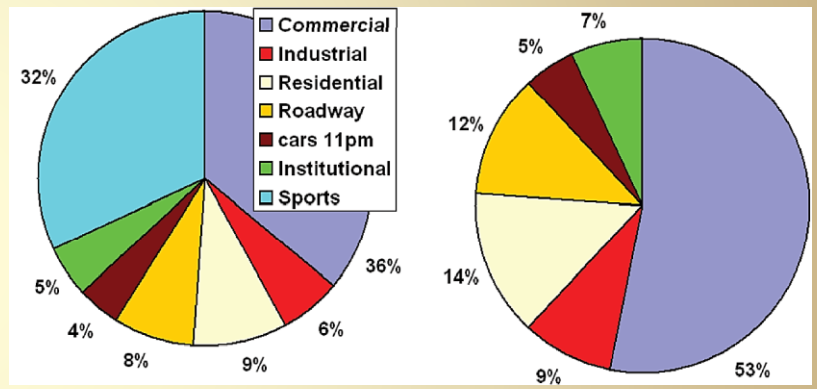
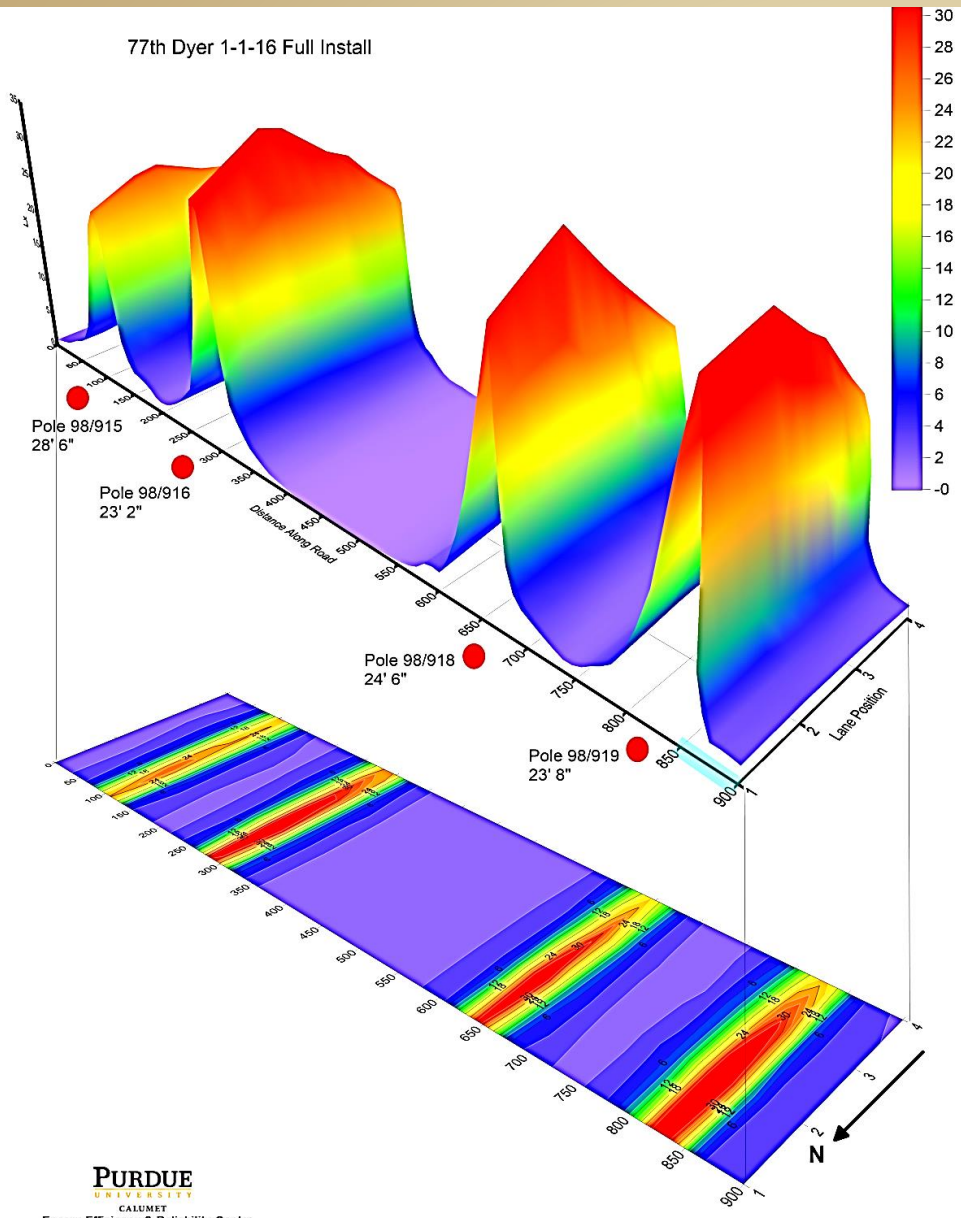
*Permissible exposure times (PET) are not defined for weighted radiance < 100 W m⁻² sr⁻¹

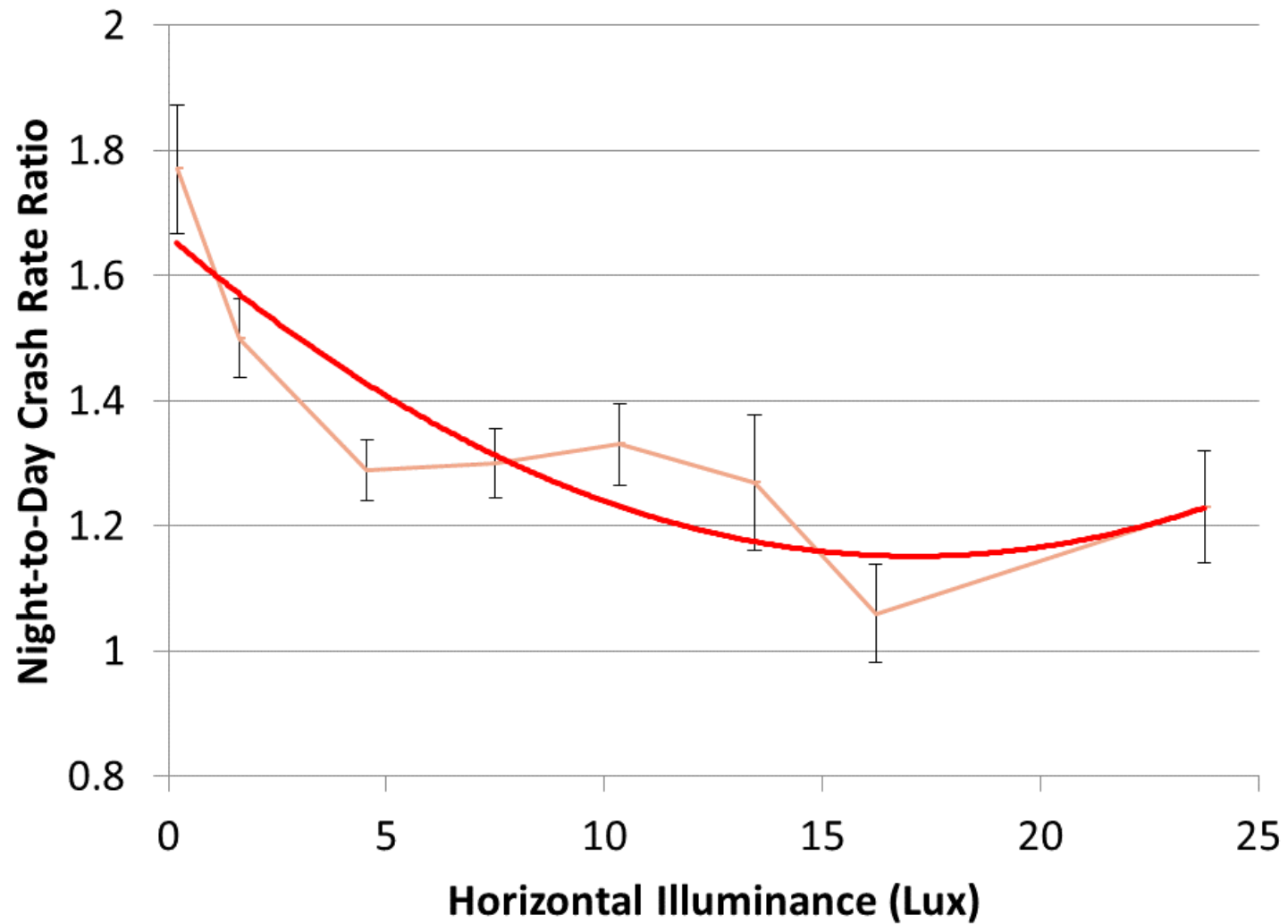
†Permissible exposure times are not defined for small sources (<0.63°) for weighted irradiance < 1 W m⁻²

PET = 278 hours/ L_b for $t < 2.78$ hours or PET = 100 seconds/ E_b for $t < 100$ seconds



77th Dyer 1-1-16 Full Install





An Overview of Street Lights and Circadian Sleep Cycles

by Dr. Steven Lockley, Harvard Medical School, Division of Sleep and Circadian Disorders, and Sam Lipson, Director of Environmental Health, Cambridge Public Health Department, contributing

Our “circadian clock” is sensitive to all visible light, and any exposure to light after dusk moves us away from a natural cycle. The circadian system is more sensitive to blue light, but the intensity of light is at least as important when considering the impact of light. Just because a light source appears “bluish” does not mean it is necessarily disruptive and just because it appears “warm” does not mean that it is not disruptive. Light wavelength and intensity interact to determine the effect of light on circadian rhythms and sleep-wake cycles.

- When considering the effects of light at night, indoor lighting is typically of more concern given the intensity and proximity of the light sources to the eyes, which detect the light. The quantity of light emitted by streetlights, both High-Pressure Sodium (HPS) and LED, is many times lower than that emitted by typical interior lights, TVs, tablets, or PC screens.
- Studies on the effect of blue light and recent articles that warn about health issues associated with light exposure at night refer primarily to device screens and interior light sources as having possible negative impacts. These risks are primarily based on lighting associated with night-shift work.
- Research suggests that the light levels from streetlights (both HPS and LED) are simply too low to cause significant negative circadian or sleep health problems, especially if the light reaching the eye is further reduced by curtains, eye masks or closing the eyes to sleep. There is no evidence that typical exposure to street lights of any color is disruptive to the human circadian system.
- These new LEDs are slightly “bluer” than the old HPS streetlights and are estimated to have about 20% more of the stimulatory blue wavelengths before the dimming program was implemented.
- It is important to emphasize when interpreting these percentages that the absolute amount of light generated by the new LED street lights (or the old HPS street lights for that matter), that reaches the inside of residences, is very low and would not be expected to have a meaningful impact on alertness or sleep.

Illuminating Engineering Society (IES)

Board Position Paper

- The IES is aligned with the AMA in support of the proper conversion of outdoor area and roadway lighting to LED light sources to reduce energy consumption, with proper optics and shielding to reduce glare and light trespass. The IES further supports the AMA recommendation to consider the ability to reduce light levels during off-peak periods.
- The IES respectfully disagrees with the 2016 AMA Policy H-135.927 Statement 2 and the first sentence of Statement 3 specific to limitations on spectral content for outdoor area and roadway lighting.
 - We want to emphasize, that while the principal motivators for the AMA report are understandable, the CSAPH 2-A-16 report filed as background for these statements does not provide sufficient evidence to substantiate these statements, and a more comprehensive analysis of the public health impacts of outdoor and roadway lighting should be considered prior to adopting policies that could have a negative effect on the safety of drivers and pedestrians.
 - Given the state of current knowledge, it is not possible to weigh the probabilities of health care concerns regarding light-at-night and its effect on sleep disruption from outdoor and roadway lighting against the needs of nighttime driver and pedestrian safety, but such deliberations should precede any policy statement that affects both concerns.

IES Board Position Paper

- The IES also disagrees with 2016 AMA Policy H-135.927 on the basis that Correlated Color Temperature (CCT) is inadequate for the purpose of evaluating possible health outcomes; and that the recommendations target only one component of light exposure (spectral composition) of what are well known and established multi-variable inputs to light dosing that affect sleep disruption, including the quantity of light at the retina of the eye and the duration of exposure to that light.
- A more widely accepted input to the circadian system associated with higher risk for sleep disruption and associated health concerns is increased melanopic content, which is significantly different than CCT.
 - LED light sources can vary widely in their melanopic content for any given CCT; 3000 K LED light sources could have higher relative melanopic content than 2800 K incandescent lighting or 4000 K LED light sources, for example.
 - Common household incandescent lighting could therefore have significantly higher melanopic dosing than 3000 K outdoor or roadway lighting at night due to relatively higher melanopic content, higher light levels and longer durations of exposure.
- For all the listed reasons, the upper CCT limit of 3000 K contained in AMA Policy H-135.927 lacks scientific foundation and does not assure the public of any certainty of health benefit or risk avoidance.

Thank You!

Robert Kramer, Ph.D., CEM, CDSM, CEA
Director, Energy Efficiency and Reliability Center
NiSource Charitable Foundation Professor of Energy and the Environment
Professor of Physics
Purdue University Northwest
219-989-2147
kramerro@pnw.edu